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ON THE VISUAL TRACKING OF TWO BRIGHT SATELLITES FROM C-130-TYPE AIRCRAFT

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by

Richard C. Vanderburgh

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ON THE VISUAL TRACKING OF TWO BRIGHT SATELLITES

FROM C-130-TYPE AIRCRAFT[1]

Richard C. Vanderburgh[2]

To determine the general feasibility of airborne visual satellite-tracking, I made five flights aboard USAF C-130 aircraft (see figure 1). This was a preliminary step toward the development of a reliable and economic means of tracking low, unstable satellites.

Newly launched and rapidly decaying satellites are often inadequately tracked because (a) fixed ground sensors do not have line-of-sight to critical portions of the earth envelope, and (b) these operations are often hampered by poor weather and poor visibility. A decaying satellite presents the larger problem because of its consistently low altitude and increasing instability. Although difficult phases of new launches are usually adequately prepared for by pre-launch positioning of ground sensors, improper orbit injections can render existing ground sensors inadequate. Because he can locate himself at positions of optimum weather and satellite illumination, the airborne observer can provide orbit analysts with vital data at critical times.

The flights described here were made possible through the courtesy of the 3245th Air Base Wing, L. G. Hanscom AFB, Bedford, Massachusetts. Since our equipment included only that provided by the operational aircraft, missions were restricted to relatively simple exercises. Our targets were the two bright balloon satellites, 1961 Delta 1 (Explorer IX) and 1960 Iota 1 (Echo I), as they afforded easy acquistion and their continuous orbit maintenance by SAO helped us to check our accuracy. Although no stable satellites can be realistically substituted for unstable ones, the two balloons served well as practical targets to test experimental prediction and observation techniques.

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[1]Supported by grants NsG 4am and NsG 563 from the National Aeronautics and Space Administration.

[2]Chief, Moonwatch Division, Smithsonian Astrophysical Observatory.

Our over-all accuracy was about what we expected, considering the uncontrollable errors introduced by altitude-azimuth reference instability and the uncertainty of aircraft position. Significant reduction of these errors would require such refinements as precision gyro stabilization of the aircraft or of the observing instrument references, and the most advanced air navigation equipment. If airborne observing serves primarily as a critical source for the improvement of only the true anomaly, however, great accuracy is not so important as it would be if all other orbital elements also had to be improved. For both new and old unstable satellites, theoretical computations combined with sparse but accurate ground-sensor data are usually sufficient for definition and extrapolation of the basic orbit plane parameters (node, inclination, argument of perigee, and, to a limited extent, semimajor axis and eccentricity). By comparison, true anomaly (translated into mean anomaly or mean motion) extrapolations are usually poor because of the unpredictable effects of air drag (especially significant for low orbits). Therefore the availability of comparatively inaccurate airborne observations, at critical times when no ground-sensor data exist, can help to keep mean motion under control; by careful, indirect application, the analyst can refine the other orbital elements. Obviously, an observation in error by as much as five seconds (time) is of value when the extrapolated mean motion is in error by five minutes.

Shadow-entry observations, which can significantly help to fill the need for determining the mean motion, are especially easy to obtain from aircraft. The observer simply acquires the satellite in his optical instrument and follows the image to shadow entry, noting only the time of the event. He need record neither satellite nor aircraft position, since true anomaly can be determined from the intersection of orbit periphery and the earth-shadow cone at the observed shadow-entry time. Although a few unusual combinations of satellite inclination and sun declination can produce either continuous satellite illumination or poorly defined shadow thresholds, most anticipated conditions would yield definable shadow entries.

Sunset phenomena observed by U. S. astronauts (NASA, 1962) indicate that the transition from the bright solar disc to a bright horizon illumination is fairly rapid, although the illumination itself lasts for several minutes. Thus the timing of the first detectable dimming that is not due to tumbling would represent the disc-to-ribbon transition and would yield a nicely definable event. Shadow entries during the flights described here were recorded as altitude-azimuth events at total disappearance and were treated as such for accuracy determination Realistic evaluation of shadow-entry observing techniques would require special data-reduction programs that would quickly define theoretical shadow thresholds.

Flight schedules

All five flights originated at Hanscom AFB, Bedford, Massachusetts. They were conducted between 28,000 and 30,000 feet, the optimum range for the aircraft, considering over-all stability. We expected to top clouds except for occasional thin cirri. Each mission was to be five to six hours long. Normal cruising speed for the C-130 is about 280 knots; winds gave a ground speed ranging from 240 to 310 knots.

We conducted the first flight in the vicinity of the Lac des Loupes radio beacon (47°N $76^{\circ}30'$W). While on location, the aircraft was to follow a "racetrack" pattern, maintaining constant headings while observations were in progress.

The remaining flights,conducted over water off the eastern United States seaboard, proved more satisfactory, because maneuvering requirements for air-traffic control here were less stringent than those over the continent. We made flights 2 through 4 between Boston and Sable Island (44°N 60°W) and flight 5 between Boston and the vicinity of 38°N 70°W.

A few days before each proposed flight, I consulted the latest ephemerides (SAO Ephemeris 6) of satellite parallel crossings, and, from satellite paths and probable aircraft positions, made nominal look-angle predictions. We scheduled flight 1 to coincide with two transits of Echo I; flights 2 through 4, with three successive transits of Echo I; and flight 5, with one transit of Explorer IX and one of Echo I. We attempted to position the aircraft within orbit planes only for the one Explorer IX transit. For the other transits, we secured sufficient aircraft proximity to orbit planes to obtain elevated satellite positions.

I used the experience from the first two flights to outline the prediction and observation record forms for subsequent missions (forms 1 and 2). A simple analog aid consisting of a meridional net and multiple rotatable overlays helped me to calculate useful satellite revolutions and best aircraft times and positions from parallel-crossing ephemerides (SAO Ephemeris 6).

Observing equipment

The military model of the Kollsman Periscopic Sextant 1287 series was the optical instrument used on all flights (see figure 2). This instrument, normally used in celestial navigation, is standard equipment aboard commercial and military aircraft flying overseas. The following extract from the Pan American World Airways Pacific Navigation Manual describes its general characteristics:

. . . a sextant incorporating a periscopic optical system. It permits the navigator to make observations from within the cabin by projecting the periscope beyond the skin of the aircraft through a specially designed opening and mount. This feature eliminates the astrodome--necessary with the present standard hand-held sextants along with its inherent complications such as structural difficulties, distortion of line of sight and disturbance of air flow.

The optical system of the sextant will permit observations of celestial bodies through 360 degrees in azimuth and from minus 10 to 92 degrees in elevation. The sextant has a true field of vision of 15 degrees with a magnification of two power and an exit pupil of 4.5 mm. By using coated optics a high light transmission is obtained which gives visual brightness approximately equal to a 7 mm. exit pupil with uncoated lenses. The ocular has an adjustable focus of -2 to plus 2 diopters with a soft rubber eyeguard to protect (and shield) the observer's eye.

The optics in the periscope section of the instrument are hermetically sealed with dry air to prevent moisture condensation when the upper section of the periscope is in colder air.*

. . . The line of sight is rotatable in elevation, within an accuracy of two minutes, by tilting the reflecting surface of the index prism, which is at the entrance window of the instrument . . . . The altitude angle of the celestial body is obtained when the instrument is adjusted so that the image of the celestial body and the horizon line (or bubble center) coincide. The sextant optics are so designed that the matching of the celestial body and horizon line (or bubble) need not necessarily be in the center of the field of view as they will remain in the field of vision up to an angle of 6 degrees from the center of the optical axis of the sextant.

The military mount (figure 3) is so constructed that the look-angle of a sighted object can directly indicate the true heading of the aircraft. The observer must know the true azimuth of the object of interest and set it into the digital readout window by turning the hand-cranked gear train. I used this procedure to determine the true aircraft headings from Polaris before and after each satellite transit.

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*The horizon reference on commercial models is an illuminated line projected into the field of view. The line is formed by reflection from a liquid-damped pendulous mirror. In military models, the horizon reference is a bubble whose size can be varied as desired.

For satellite observations we set the azimuth ring to zero to get reversed relative bearings* for satellite directions. Fittings on the periscopic tube guide it through an airlock in the mount and engage an azimuth reference line that moves when the instrument is turned about the vertical axis. A small segment of the azimuth circle that contains the reference line is illuminated externally; its image projects into the sextant optics (figure 2b).

The commercial mount has a manually adjustable azimuth circle, which can be set with reference to a lubber line **. Since the scale is not projected into the sextant optics, readings must be made externally by examination of the intersection of the sextant reference line and the azimuth scale.

We used stopwatches in conjunction with navigator's master watches (set to radio time signals) to record satellite fix times. We determined aircraft position by using loran, radar, and other standard air navigation aids.

Observing procedures

From our experience with the five flights, we developed the following observing procedures:

1. Using the SAO Ephemeris 6, the Air Almanac, analog aids, dead-reckoning positions, and the prediction planning form (form 1), the observer computes satellite look-angles and the azimuth of Polaris (or other suitable celestial bodies).

2. About ten minutes before he begins to look for the satellite, the observer shoots Polaris, calling off bearings to an assitant, who simultaneously records them and the ship's compass readings.

3. Using the Polaris-determined true heading of the aircraft and the predicted azimuth of the satellite (at acquisition), he computes the reversed relative bearing (-RB).

4. The observer then sets the mount counter to zero and the computed satellite altitude into the periscopic sextant and, by turning the instrument, sets it on the desired reversed relative bearing.

5. One assistant is briefed to record ship's compass readings and the -RB as called over the interphone system by the observer. Another assistant is briefed to record sextant altitude readings and to exchange stopwatches with the observer after each fix.

*At nose, 0°; at port wingtip, 90°; at tail, 180°; at starboard wingtip, 270°.

**Aircraft longitudinal axis reference.

6. Alternately illuminating the sextant field of view for horizon reference and darkening it for object acquisition, the observer begins his patrol at the predicted time. Upon acquistion he makes as many fixes as he can, depending on his assistants' recording speed.

7. To obtain a good fix, the observer presets the sextant altitude adjustment to allow the satellite image to drift through the center of the bubble, which, in turn, is centered in the field of view. The observer calls "mark" at the event time, simultaneously starting a stopwatch; then he calls out the -RB, waits for confirmation that it and the altitude have been recorded, and receives a new stopwatch. Because the satellite may have drifted out of the field of view during recording operations, the observer proceeds to "find" it again, and then initiates additional fixes.

8. As fixes are made, the assistants record data on the observation form (form 2), with three lines to each fix. They enter -RB figures on the second line in the azimuth column, altitude on the first line of the altitude column, and stopwatch-elapsed time on the second line of the time column. The Universal Time at which each watch is stopped is entered on the first line of the time column. The difference between lines 1 and 2 gives the UT of the event. The ship's compass reading is entered after "COMP:."

9. When the satellite is no longer visible, the observer makes another Polaris check. These readings before and after satellite observing are entered at the bottom of form 2.

10. In order to complete the remainder of the observation form, the observer subtracts reversed relative bearings from true headings to obtain true azimuths; applies refraction, coriolis, and rhumbline corrections to sextant altitude to obtain observed altitude; and computes latitude, longitude, elevation, ground speed, and true course for each event time.

Results

Echo I was the easier object to acquire, although at low elevation it often took the observer half a minute or so to identify it, because of its slow motion.

Explorer IX was barely bright enough to acquire at a slant range of 1000 km (20° elevation; sun 15° below). As the satellite approached the zenith (400-km slant range), it moved through the sextant field too fast to permit reacquisition after recording delays before entering the earth's shadow immediately past zenith. Continuous tracking would have been practicable at even higher apparent velocities, if I had not had to hold the sextant steady for a moment following each fix for recording.

The main disadvantages of the sextant used are the relatively restricted apparent field of view, the small aperture, and the field-obscuring by the bubble. I found no use for the averaging device during this exercise. As a horizon reference, the bubble (or commercial model illuminated line) is susceptible to false indication caused by aircraft accelerations.

Table 1 is a compilation of observational data, with corresponding positional accuracy derived from DOI* output. Each root mean-square entry is the vector difference (in seconds of arc) between observed and computed satellite positions at observed times.

Table 2 is a facsimile of the complete DOI output, including interspersed Baker-Nunn camera observations. Only Baker-Nunn observations were used to produce the computed orbit. Orbital elements used are presented on the first line, in the following order: argument of perigee; node; inclination; eccentricity; true anomaly; number of revolutions per day; semimajor axis (megameters); perigee radius; and perigee height. Column headings are (1) observation number; (2) station number; (3) station weight (assigned standard error); (4) time (MJD); (5) slant range (from observer to satellite) in megameters; (6) computed mean anomaly at observation time; (7) observed minus computed true anomaly; (8) declination or altitude residuals; (9) right ascension or azimuth residuals.

As would be expected, practice improved quality. The root mean-square figures in table 1 show observing errors of 3 to 16 degrees for the first 10 observations. Of the next 24 observations, 19 were under two degrees; 12, under one degree. The large residuals of the next 6, constituting all of one transit, probably result from inadvertent instrument-setting or recording errors. By flight 4, each member of the observing team was sufficiently proficient to help keep the cumulative observational errors consistently low, except for one transit, during which observing duties were exchanged. In positional accuracy the five observations made by Captain Jochum compare closely with my first five.

Conclusions ~~76724~~ A

While more developmental, experimental,and organizational work is still required before a sound operational approach to airborne satellite tracking can be effected, the exercise herein described shows what can be done with unmodified operational aircraft and quickly trained observers. The methods used and the techniques developed should work well with higher-performance aircraft and specialized observing equipment to produce a greater observing capability with higher accuracy.

*SAO Differential Orbit Improvement Program. A Special Report describing this program is now in preparation.

Acknowledgements

I am sincerely grateful to the many Air Force personnel at Hanscom Field who helped to make possible the five C-130 flights. I also thank Arthur S. Leonard (professor of agricultural engineering at the University of California) and Leonard Solomon (chief of the SAO Data Division) for their technical assistance.

Reference

NASA
1962. Results of the First and Second United States Manned Orbital Space Flight, NASA Manned Spacecraft Center Project Mercury, pp. 126-129 (February 20), and pp. 34-41 (May 24).

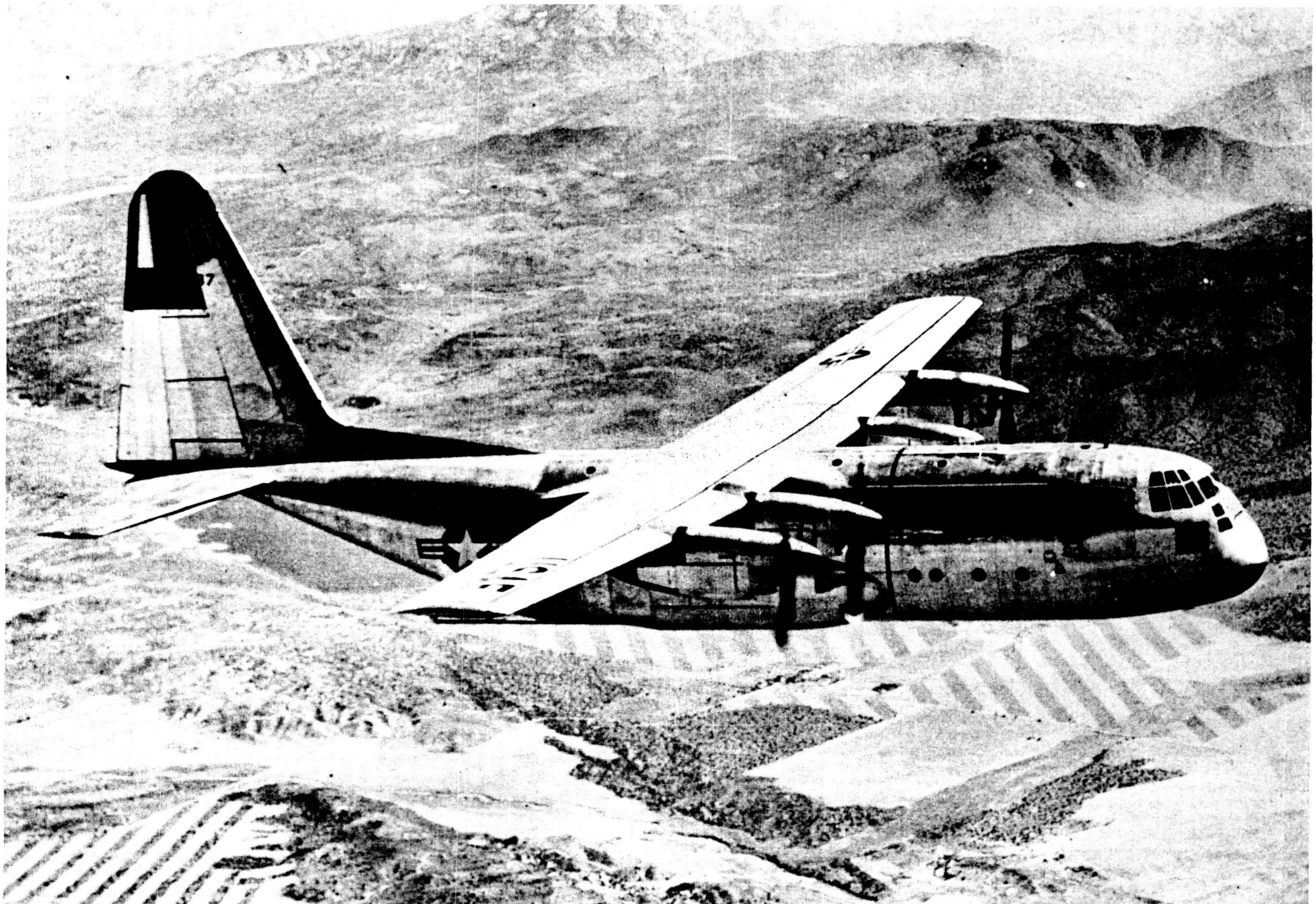
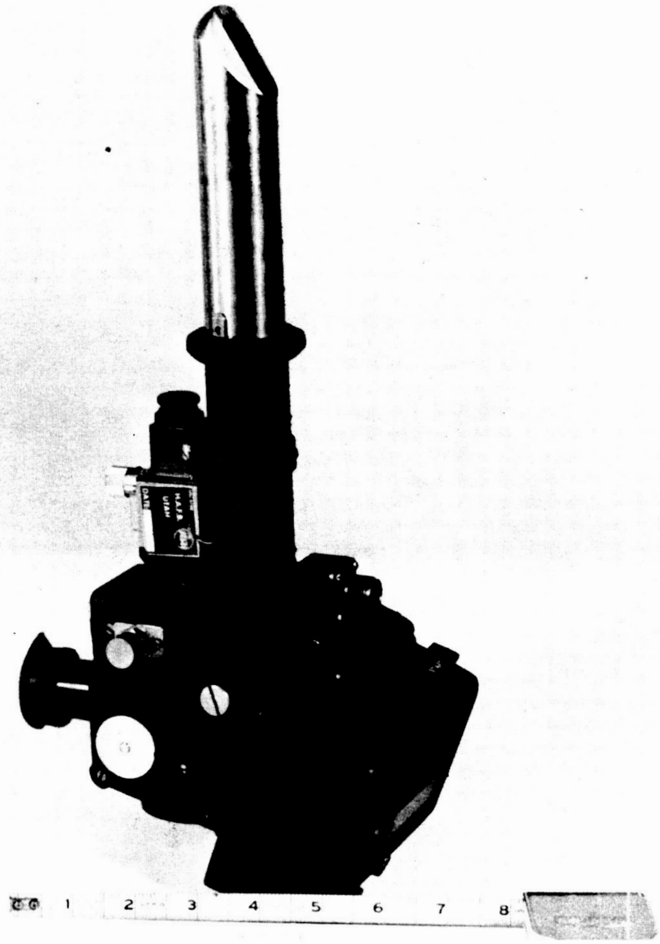
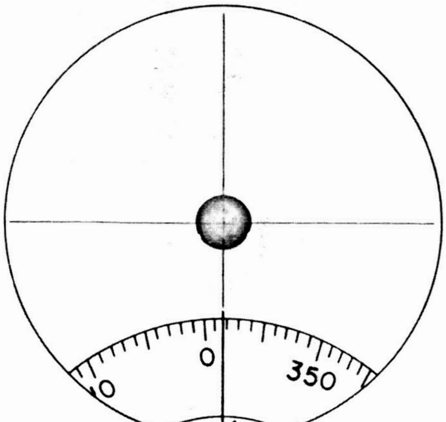


Figure 1.---C-130 turbo-prop military transport aircraft.



2a



2b

Figure 2.--(a) Kollsman Periscopic Sextant. (b) Periscopic sextant field of view.

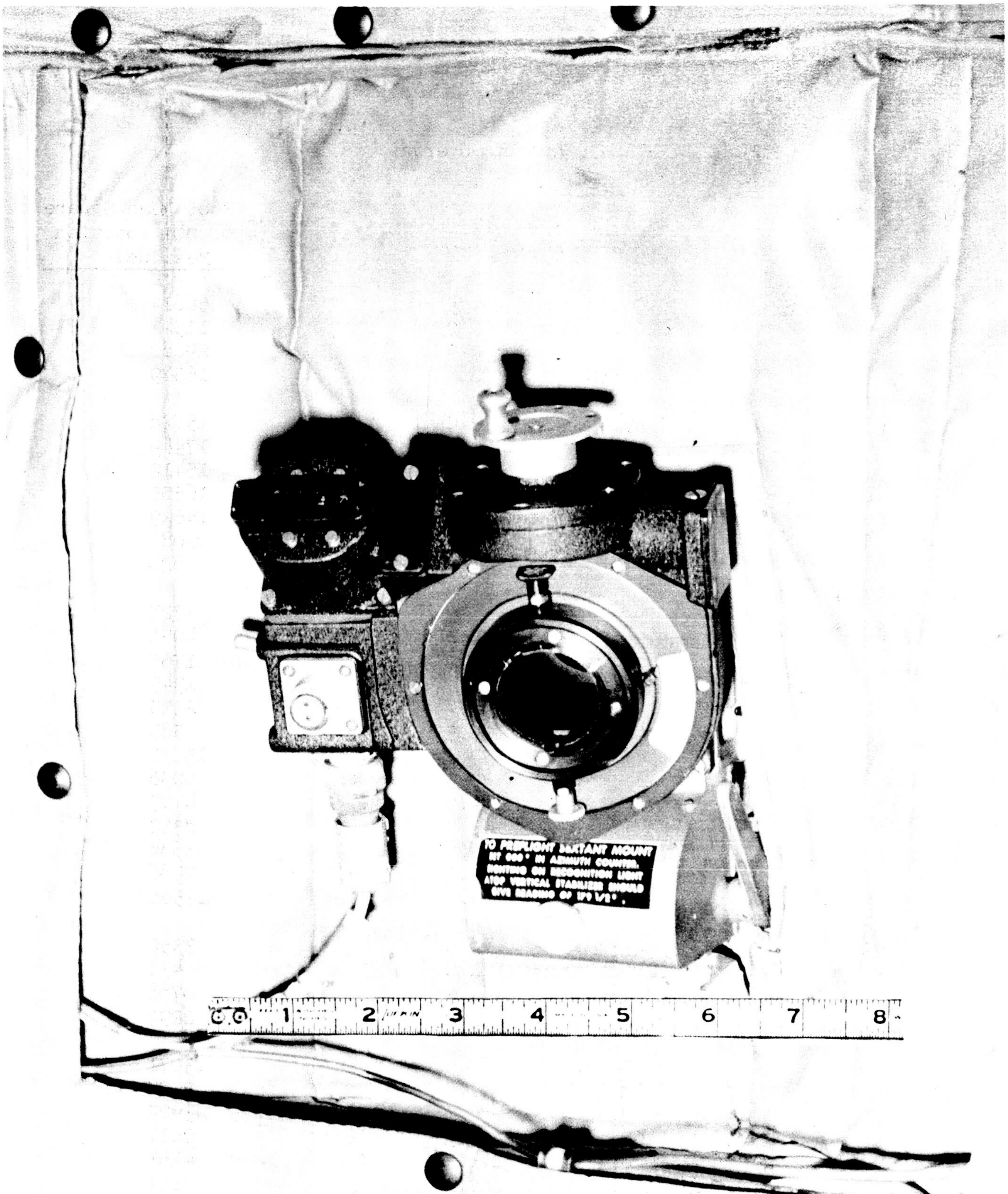


Figure 3.--Periscopic sextant mount (in the ceiling of the aircraft).

Table 1.--Tabulation of observations

	Date	Object	Time (UT)	Azimuth	Altitude	Root Mean-Square of DOI Position Residuals
Flight 1	7 Sept	Echo I	0107:57.4	074.5	20.0	56814
			0108:14.9	066.0	03.7	11527
			0246:45.6	236.5	14.6	29680
			0253:50.2	226.8	61.2	16549
	11 Sept		2329:43.5	162.0	70.2	15828
			2331:38.0	100.5	64.7	17449
			2333:52.0	081.2	53.3	15412
			2334:11.0	077.0	45.1	16505
			2335:29.0	072.5	37.9	14639
			2337:21.9	068.0	26.8	12089
			2347:13.5	065.5	08.9	828
Flight 2	12 Sept		0132:28.5	274.4	22.7	3728
			0134:20.9	276.0	32.2	4051
			0135:41.4	279.8	42.9	1765
			0137:20.2	286.4	57.3	1345
			0138:27.8	299.4	67.2	2325
			0142:34.2	065.5	61.0	585
			0143:33.0	077.5	52.6	13232
			0144:35.3	077.5	44.6	6056
			0146:12.7	079.0	35.1	4479
			0331:04.0	291.5	16.6	8352
			0332:13.9	292.2	22.3	5684
			0334:50.8	295.2	35.8	3486
		Shadow entry	0341:16.3	045.8	71.9	13566
Flight 3	19 Sept		2302:39.5	022.5	68.1	3350
			2306:40.1	061.8	37.1	431
			2308:42.5	065.4	28.1	8788
			2312:32.3	072.0	11.4	2293
	20 Sept		0102:47.9	287.5	39.2	13071
			0103:51.0	287.2	53.1	2978
			0104:59.9	288.1	65.6	3922
			0106:24.1	292.5	82.0	2611
			0108:41.2	104.2	70.1	4161
		Shadow entry	0109:33.5	107.2	59.7	7111
			0257:28.2	282.5	14.0	39151
			0258:38.6	280.8	20.1	40504
			0258:59.3	280.0	24.5	42700
			0301:27.8	276.5	36.0	36134
			0302:48.3	272.5	45.2	32051
		Shadow entry	0304:23.3	264.0	58.6	22366

Table 1.--Tabulation of observations (continued)

	Date	Object	Time (UT)	Azimuth	Altitude	Root Mean-Square of DOI Position Residuals
Flight 4	24 Sept	Echo I	2334:41.8	288.8	18.8	4684
			2336:31.8	291.3	31.2	9757
			2338:08.3	298.8	42.2	4273
			2339:17.8	307.4	53.2	2280
			2341.00.5	334.8	68.3	3447
			2342:03.2	018.5	72.1	1914
			2343:31.8	062.5	64.6	2742
			2346:46.2	087.5	38.4	108
			2347:46.6	090.7	32.7	926
			2348:56.7	092.2	27.0	3632
		Shadow entry	2349:40.1	093.0	23.9	4817
	25 Sept		0140:19.2	271.5	28.4	27102*
			0141:17.7	266.5	34.2	25786*
			0142:38.9	258.0	41.7	19555*
			0143:15.6	249.3	44.0	26043*
			0144:19.0	236.5	48.4	23297*
			0334:38.7	286.3	07.3	5013
			0335:42.1	283.3	10.7	3847
			0336:21.0	281.1	12.6	3348
			0337:16.0	277.0	15.6	4730
			0338:00.2	274.8	17.4	1761
		Shadow entry	0339:21.1	267.0	21.9	2819
Flight 5	14 Oct	Explorer IX	2318:05.8	276.5	28.7	
			2318:53.1	274.8	49.6	
			2319:26.1	263.0	77.1	
	15 Oct	Echo I	0002:16.9	229.0	05.9	
			0003:09.7	224.0	05.7	
			0004:05.5	219.0	05.5	
			0004:47.8	215.3	04.8	
			0005:45.4	210.3	04.3	
			0006:48.3	205.3	03.4	
			0009:50.1	194.0	-00.3	

*Observations made by USAF Navigator Captain Arthur Jochum.

Table 2.--DOI facsimile

PER.	NODE	INCLINATION	ECC.	ANOMALY	N	A(MM)	Q(MM)	Q'(MM)
285.76635	238.64131	47.29520	.061411	.485882	12.530565	7.829421	7.348605	.980941

OBS.	STA.	RS(S)	TIME(UT)	RHO	MA	DM(REV)	DEC(S)	RA(S)	
12798	9009	150.	38279.033666	2.886	.317	.863E-4	289.	11.	
- 40001	50	5399.	38279.047192	4.838	.487	-.0224810	53986.	17700.	FLIGHT # 1
40002	51	5399.	38279.047395	4.917	.489	.0024085	-1900.	-11369.	
12773	9004	150.	38279.050617	2.259	.530	-.62E-5	-79.	-62.	
12761	9001	150.	38279.115548	1.756	.343	.704E-4	258.	273.	
- 40003	52	5399.	38279.115805	3.702	.346	.0023137	949.	-29665.	7 SEPT 63
- 40004	53	5399.	38279.120720	2.065	.408	.0015728	580.	-16539.	
12774	9004	150.	38279.135466	1.918	.593	-.90E-5	-100.	-95.	
12762	9001	150.	38279.200446	2.339	.407	.563E-4	150.	182.	
12800	9010	150.	38279.206596	3.227	.484	.273E-4	103.	64.	
12763	9001	150.	38279.287035	2.708	.492	.418E-4	-35.	149.	
12801	9010	150.	38279.293668	2.583	.575	-.346E-4	86.	-121.	
12781	9007	150.	38279.388183	2.946	.759	-.0001016	332.	-176.	
12820	9005	150.	38279.435571	1.808	.353	.763E-4	262.	300.	
- 40005	54	5399.	38283.978976	2.471	.284	.0446906	50918.	-149862.	
- 40006	55	5399.	38283.980301	2.079	.301	.0440405	-112497.	-133379.	FLIGHT # 2
- 40007	56	5399.	38283.981852	1.805	.320	.0314546	-130212.	-82456.	
- 40008	57	5399.	38283.982072	1.789	.323	.0331067	-146347.	-76312.	
- 40009	58	5399.	38283.982974	1.790	.334	.0266636	-134102.	-58715.	
- 40010	59	5399.	38283.984281	1.969	.351	.0204988	-113713.	-41046.	
40011	60	5399.	38283.991128	4.409	.436	-.0001305	529.	-637.	
12889	9008	150.	38284.008566	2.855	.655	.556E-4	26.	309.	
40012	61	5399.	38284.064219	3.172	.352	.0003639	805.	3640.	
40013	62	5399.	38284.065520	2.691	.369	-.0009020	-4051.	-51.	
40014	63	5399.	38284.066451	2.393	.380	.0001547	259.	1746.	
40015	64	5399.	38284.067595	2.103	.395	.0002574	1342.	-82.	
40016	65	5399.	38284.068377	1.973	.404	-.305E-4	-1388.	1865.	
40017	66	5399.	38284.071229	2.106	.440	-.341E-4	379.	446.	
40018	67	5399.	38284.071910	2.266	.449	.0006432	-1.	13232.	
40019	68	5399.	38284.072631	2.470	.458	.0002686	210.	6052.	
40020	69	5399.	38284.073758	2.845	.472	-.0009949	4449.	516.	
12871	9002	150.	38284.093092	3.255	.714	.201E-4	2.	97.	
12872	9002	150.	38284.099505	2.702	.794	.251E-4	-53.	100.	
40021	70	5399.	38284.146574	3.631	.384	.0001861	-1331.	8245.	
40022	71	5399.	38284.147383	3.314	.394	.0004389	273.	5677.	11-12 SEPT 63
40023	72	5399.	38284.149199	2.667	.417	-.0007943	-3457.	-449.	
40024	73	5399.	38284.153661	2.027	.473	-.0028425	9155.	-10011.	
12894	9001	150.	38284.232940	2.861	.466	-.130E-4	84.	148.	
12898	9012	150.	38284.304747	3.575	.366	-.0001515	-383.	89.	
12895	9001	150.	38284.312664	2.998	.466	-.812E-4	-203.	-245.	
12899	9012	150.	38284.390631	3.847	.443	-.0001049	-250.	82.	
12900	9012	150.	38284.392024	3.735	.460	-.917E-4	67.	263.	
12901	9012	150.	38284.567138	2.152	.654	.141E-4	-61.	42.	
- 12902	9008	150.	38284.702492	2.548	.351	-.0013657	-4772.	-1436.	
- 12897	9006	150.	38284.707801	3.016	.417	-.0002216	-678.	-204.	

Table 2.--DOI facsimile (continued)

PER.	NODE	INCLINATION	ECC.	ANOMALY	N	A(MM)	Q(MM)	Q'(MM)
323.94199	205.41270	47.26920	.059471	.799965	12.532353	7.828675	7.363095	.988715

OBS.	STA.	RS(S)	TIME(UT)	RHO	MA	DM(REV)	DEC(S)	RA(S)
13011	9002	150.	38291.035177	2.138	.709	-.75E-5	4.	-44.
13012	9002	150.	38291.036082	2.238	.720	.270E-4	-71.	114.
13013	9002	150.	38291.114543	2.807	.703	-.244E-4	50.	-175.
13024	9001	150.	38291.166243	2.695	.351	.24E-5	8.	2.
13025	9001	150.	38291.167877	2.529	.372	.211E-4	94.	119.
13026	9001	150.	38291.169158	2.559	.388	.34E-7	7.	22.
13027	9001	150.	38291.250505	2.663	.407	.153E-4	31.	57.
13019	9011	150.	38291.274007	2.859	.702	-.50E-5	19.	-8.
13094	9012	150.	38291.329231	3.528	.394	.14E-5	23.	-33.
13021	9011	150.	38291.353772	2.604	.701	.24E-5	-22.	-1.
13014	9007	150.	38291.354032	1.808	.705	.238E-4	-167.	-0.
13015	9007	150.	38291.355887	1.956	.728	.26E-5	-48.	-16.
13022	9011	150.	38291.357236	1.522	.745	-.30E-5	74.	34.
13023	9011	150.	38291.358075	1.483	.755	-.116E-4	90.	-43.
13029	9005	150.	38291.401763	2.087	.303	.41E-5	31.	-4.
13030	9005	150.	38291.404465	2.541	.337	.105E-4	-38.	23.
13031	9005	150.	38291.485527	2.421	.352	.0073393	35728.	-1700.
13032	9005	150.	38291.489606	2.456	.404	.100E-4	-64.	-46.
13060	9008	150.	38291.640166	2.586	.290	.31E-5	12.	-31.
13061	9008	150.	38291.641814	2.685	.311	-.359E-4	128.	40.
13062	9008	150.	38291.724741	2.929	.350	-.31E-5	-10.	-6.
13063	9008	150.	38291.728681	2.845	.400	.137E-4	-50.	-20.
13064	9008	150.	38291.808298	3.060	.397	.73E-5	-18.	54.
13028	9004	150.	38291.884611	2.263	.354	-.73E-5	-43.	-4.
40047	74	5399.	38291.960179	1.712	.301	.0003212	-3348.	-104.
40048	75	5399.	38291.962964	2.441	.336	.313E-4	-288.	-321.
40049	76	5399.	38291.964381	2.974	.354	-.0019570	7889.	-3873.
40050	77	5399.	38291.967040	4.066	.387	-.807E-4	779.	2157.
13037	9002	150.	38291.992853	3.302	.710	.117E-4	20.	66.
40051	78	5399.	38292.043610	2.295	.347	-.0026544	-13046.	-805.
40052	79	5399.	38292.044340	2.089	.356	.0004936	2459.	-1680.
40053	80	5399.	38292.045138	1.921	.366	.0007616	3872.	-622.
40054	81	5399.	38292.046112	1.815	.378	.0004923	2465.	860.
40055	82	5399.	38292.047699	1.913	.398	.0006381	-3395.	-2405.
40056	83	5399.	38292.048304	2.031	.405	.0014030	-7080.	660.
13041	9001	150.	38292.122258	2.534	.332	-.210E-4	-86.	-24.
40057	84	5399.	38292.123243	3.673	.344	.0025928	-2526.	-39069.
40058	85	5399.	38292.124058	3.343	.355	.0036073	110.	-40524.
40059	86	5399.	38292.124297	3.246	.358	.0062248	9738.	-41575.
40060	87	5399.	38292.126016	2.618	.379	.0034037	-492.	-36130.
40061	88	5399.	38292.126948	2.331	.391	.0027902	-3112.	-31900.
40062	89	5399.	38292.128047	2.072	.405	.0023483	-2938.	-22308.
13042	9001	150.	38292.204734	2.838	.366	-.214E-4	-76.	-35.
13038	9007	150.	38292.312445	2.370	.716	.24E-5	12.	17.
13040	9011	150.	38292.313971	1.899	.735	.15E-5	74.	49.

FLIGHT #3

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Table 2.--DOI facsimile (continued)

PER.	NODE	INCLINATION	ECC.	ANOMALY	N	A(MM)	Q(MM)	Q'(MM)
339.69799	192.10130	47.25380	.058747	.931540	12.533850	7.828050	7.358176	.991180

OBS.	STA.	RS(S)	TIME(UT)	RHO	MA	DM(REV)	DEC(S)	RA(S)
13085	9002	150.	38296.061153	1.885	.698	.90E-5	-92.	-53.
13097	9012	150.	38296.273605	3.390	.361	.110E-4	-34.	23.
13086	9007	150.	38296.381099	3.392	.708	.19E-5	-7.	28.
13092	9006	150.	38296.590385	2.741	.331	.176E-4	-60.	65.
13093	9006	150.	38296.671014	2.857	.342	.401E-4	176.	59.
13087	9003	150.	38296.699736	2.379	.702	.301E-4	27.	169.
13105	9008	150.	38296.751036	2.834	.345	.431E-4	229.	47.
13088	9003	150.	38296.779038	2.229	.696	-.72E-5	38.	-10.
13089	9004	150.	38296.828609	2.061	.317	.500E-4	-165.	157.
13090	9004	150.	38296.910438	2.364	.343	-.88E-5	30.	-54.
40036	90	5399.	38296.982428	2.921	.245	-.0006388	-1850.	-4303.
40037	91	5399.	38296.983701	2.435	.261	.638E-4	3263.	-9195.
40038	92	5399.	38296.984818	2.076	.275	-.0004420	-731.	-4210.
40039	93	5399.	38296.985623	1.877	.285	-.389E-4	963.	-2067.
40040	94	5399.	38296.986811	1.713	.300	-.0005477	-367.	-3427.
40041	95	5399.	38296.987537	1.706	.309	.0003456	-39.	1914.
40042	96	5399.	38296.988562	1.818	.322	-.0001596	2362.	1392.
40043	97	5399.	38296.990812	2.431	.350	.214E-4	-92.	56.
40044	98	5399.	38296.991511	2.676	.359	-.936E-4	653.	656.
40045	99	5399.	38296.992323	2.994	.369	-.0007470	2846.	-2257.
40046	100	5399.	38296.992825	3.179	.376	-.0008255	2647.	-4025.
13095	9002	150.	38297.018407	2.061	.696	.145E-4	-62.	77.
40025	101	5399.	38297.069667	2.792	.339	.0042171	-1399.	-27066.
40026	102	5399.	38297.070344	2.583	.347	.0044340	-291.	-25785.
40027	103	5399.	38297.071283	2.340	.359	.0033174	-2212.	-19429.
40028	104	5399.	38297.071708	2.254	.364	.0041578	-7516.	-24935.
40029	105	5399.	38297.072442	2.147	.374	.0036435	-10981.	-20547.
13096	9002	150.	38297.104238	2.888	.772	.16E-5	5.	118.
13098	9001	150.	38297.148408	2.380	.326	-.0004129	-58.	-2344.
40030	106	5399.	38297.149059	4.235	.334	.0012564	17.	-5013.
40031	107	5399.	38297.149793	3.976	.343	.0011234	743.	-3775.
40032	108	5399.	38297.150243	3.825	.349	.0008738	110.	-3346.
40033	109	5399.	38297.150879	3.624	.357	.0012888	320.	-4719.
40034	110	5399.	38297.151391	3.474	.363	-.0001520	-1653.	-607.
40035	111	5399.	38297.152327	3.230	.375	.0005220	-1128.	-2583.
13103	9007	150.	38297.338670	2.980	.711	-.75E-5	22.	-21.
13106	9008	150.	38297.707229	2.468	.330	.222E-4	237.	-51.
13100	9003	150.	38297.738435	2.100	.721	-.109E-4	-64.	-52.
13101	9004	150.	38297.865894	2.100	.319	-.114E-4	3.	-63.

FLIGHT #4

24-25 SEPT 63

Form 1.

MOONWATCH HITRACK PRACTICE FLIGHTS

Satellite ________ Observer ________________ A/c Type ________
UT DATE(S) ________ Observer ________________ Wx ________

PREDICTION PLANNING

	NODE UT	NODE LONG(W)	AZIMUTH		ALTITUDE		Assumed Position	
Given			TH		Gt. ⊙		LAT	
Corr. to Lat:			AZ	-	Height		LONG	
→			-RB		ALT			

	NODE UT	NODE LONG(W)	AZIMUTH		ALTITUDE		Assumed Position	
Given			TH		G+⊙		LAT	
corr. to Lat:			AZ	-	Height		LONG	
→			-RB		ALT			

	NODE UT	NODE LONG(W)	AZIMUTH		ALTITUDE		Assumed Position	
Given			TH		G+ ⊙		LAT	
corr. to Lat:			AZ	-	Height		LONG	
→			-RB		ALT			

	NODE UT	NODE LONG(W)	AZIMUTH		ALTITUDE		Assumed Position	
Given			TH		G+ ⊙		LAT	
corr to Lat:			AZ	-	Height		LONG	
→			-RB		ALT			

Form 2.

MOONWATCH HITRACK PRACTICE FLIGHTS

Satellite ____________ Observer ____________ A/c Type ______

UT DATE(S) ____________ Observer ____________ Wx ______

OBSERVATIONS

AZ	ALT	TIME	POSITION
			LAT COMP:
			LONG
			GS TC AA
			LAT COMP:
			LONG
			GS TC AA
			LAT COMP:
			LONG
			GS TC AA
			LAT COMP:
			LONG
			GS TC AA
			LAT COMP:
			LONG
			GS TC AA
			LAT COMP:
			LONG
			GS TC AA
			LAT COMP:
			LONG
			GS TC AA
	Z+RL:	TH:	Comp | TH Comp | TH

NOTICE

This series of Special Reports was instituted under the supervision of Dr. F. L. Whipple, Director of the Astrophysical Observatory of the Smithsonian Institution, shortly after the launching of the first artificial earth satellite on October 4, 1957. Contributions come from the Staff of the Observatory. First issued to ensure the immediate dissemination of data for satellite tracking, the Reports have continued to provide a rapid distribution of catalogues of satellite observations, orbital information, and preliminary results of data analyses prior to formal publication in the appropriate journals.

Edited and produced under the supervision of Mr. E. N. Hayes and Mrs. Barbara J. Mello, the reports are indexed by the Science and Technology Division of the Library of Congress, and are regularly distributed to all institutions participating in the U. S. space research program and to individual scientists who request them from the Administrative Officer, Technical Information, Smithsonian Astrophysical Observatory, Cambridge, Massachusetts 02138.